CALIBRATION OF THE CLEMENTINE LONG-WAVE INFRARED CAMERA.

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The Clementine Mission to the Moon entered lunar orbit in February 1994 and systematically mapped the surface for 71 days through 348 orbits. The Clementine scientific payload included a Long-Wave Infrared (LWIR) camera with a single passband of width 1.5 microns centered at 8.75 microns. The LWIR camera had a 128 x 128 mercury cadmium telluride focal plane array and used a catadioptric lens. The field of view of the instrument was one degree by one degree. Preflight calibration was performed at Lawrence Livermore National Laboratory in an effort to measure camera characteristics such as: radiometric sensitivity; gain and offset scale factors; temporal-spatial noise; and dark-noise dependence on focal plane array temperature [1]. During the systematic lunar mapping phase of the mission, the spacecraft obtained approximately 239,000 thermal-infrared images.

Nighttime lunar surface temperatures are controlled by thermal inertia, while daytime temperatures depend on surface roughness and albedo. The Clementine images were obtained near local noon, and preliminary analysis of LWIR images showed a striking similarity to the Clementine Ultraviolet-Visible camera images, implying that the daytime thermal emission of the lunar surface is predominantly determined by large-scale topography [1].

We have been working on the calibration of the LWIR camera using both pre-flight and in-flight measurements. The several steps involved in the calibration effort include: identifying and eliminating bad pixels; correcting for pixel response variation across the detector array; determining the zero-flux background of the instrument; using pre-flight calibration measurements to convert measured DN values to surface radiance values; and, using in-flight measurements of areas of known temperature (such as the Apollo landing sights) to derive surface temperature values from radiance calculations.

The first step in the calibration and reduction process was to create bad pixel maps and flat fields. This was accomplished by averaging together, on a pixel-by-pixel basis, hundreds of lunar images from a single orbit. We thus generated a lunar mean image and an associated lunar standard deviation image. Bad pixels were identified on these images as pixels that: did not vary (low or zero standard deviation); varied randomly (high standard deviation); or, were pegged at high values such that their dynamic range was limited (high mean). It was also found that pixels with low means appeared bad on lunar images. Approximately 10% of the 16,384 detector array pixels were characterized as bad. A flat field frame was created by multiplying the lunar mean image and the bad pixel map, smoothing over the bad pixels, and normalizing the resultant image to unity.

Due to the varying response of the instrument and the varying characteristics of the lunar surface, several bad pixel maps and flat fields were required for each orbit. The number created was constrained by the number of lunar images over which to average. The minimum number of images to average was controlled by the need to eliminate structure due to scene variations that result from surface topography. The maximum number of images to average was limited by the varying thermal emission of the lunar surface through an orbit; the measured DN values were much higher near the equator than near the poles. Of the approximately 900 lunar images per orbit, roughly 200 images were averaged together to create the mean lunar images for southern latitudes and near the equator. Since Clementine took less images in the northern latitudes, fewer images were averaged together in these regions to create the lunar mean images.

The zero-flux level of the images increased through the orbit in response to the increasing camera temperature. Sky images (assumed to be zero-flux images) taken after the orbit were approximately 10 DN higher than those taken before the orbit. This systematic variation was corrected for by subtracting an interpolated sky image from each lunar image.

Using the techniques described above, not all bad pixels were identified. However, there appeared to be little reproducibility of a single bad pixel from frame to frame. The bad pixel routine did not identify the "railroad track" patterns seen in many images as bad pixels. We believe this is due to their shifting locations from image to image.

Our current work focuses on eliminating these "railroad track" patterns of bad pixels and refining the coefficients of the pre-flight calibration equation. By the time of the conference, we hope to incorporate Apollo landing site temperature data into our calculations and be near completion of the calibration of the LWIR camera.

After final calibration, measured DN values will be converted into lunar brightness temperatures using the Planck function. In the future, we will better constrain the thermal emission characteristics, the physical properties, and the thermal environment of the lunar surface.

REFERENCES [1] Nozette, S., *et al.* (1994). *Science* **266**, 1835-1839.

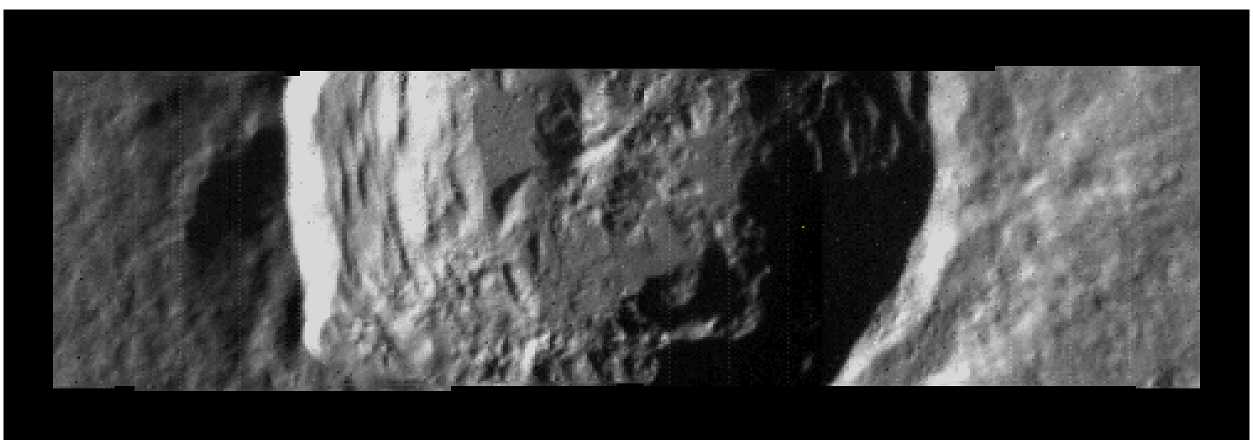

Figure 1. This LWIR image of Crater Anaxagoras (75°N, 10°W; diameter 52 km) extends 464 pixels N-S and 135 pixels E-W. East is upwards in this image.